GEOPAK: MONITORING CLIMBERS AND CLIMATE ON MOUNT EVEREST

BY

MATTHEW B. LAU

SUBMITTED TO THE DEPARTMENT OF ELECTRICAL ENGINEERING AND COMPUTER SCIENCE

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ABSTRACT

This thesis tells the tale of the *geoPak*, a device designed to collect and transmit information about its position and surrounding environment. It uses the Global Positioning System (GPS) and low power sensors to collect information about location, temperature, humidity, air pressure, and light. A radio transmitter then sends this information to a remote base station, letting people far away monitor the 'Pak. In May, 1998, the geoPak was used to monitor four climbers on Mount Everest climbing from base camp at 17,500 feet to the highest point in the world, more than two miles higher. Environmental difficulties, forced tests to terminate around 26,000 feet, but insights gained from these experiments have led to a continuation of the project with revised goals. This thesis describes the design and implementation of the first geoPak prototypes, and their testing on Everest.

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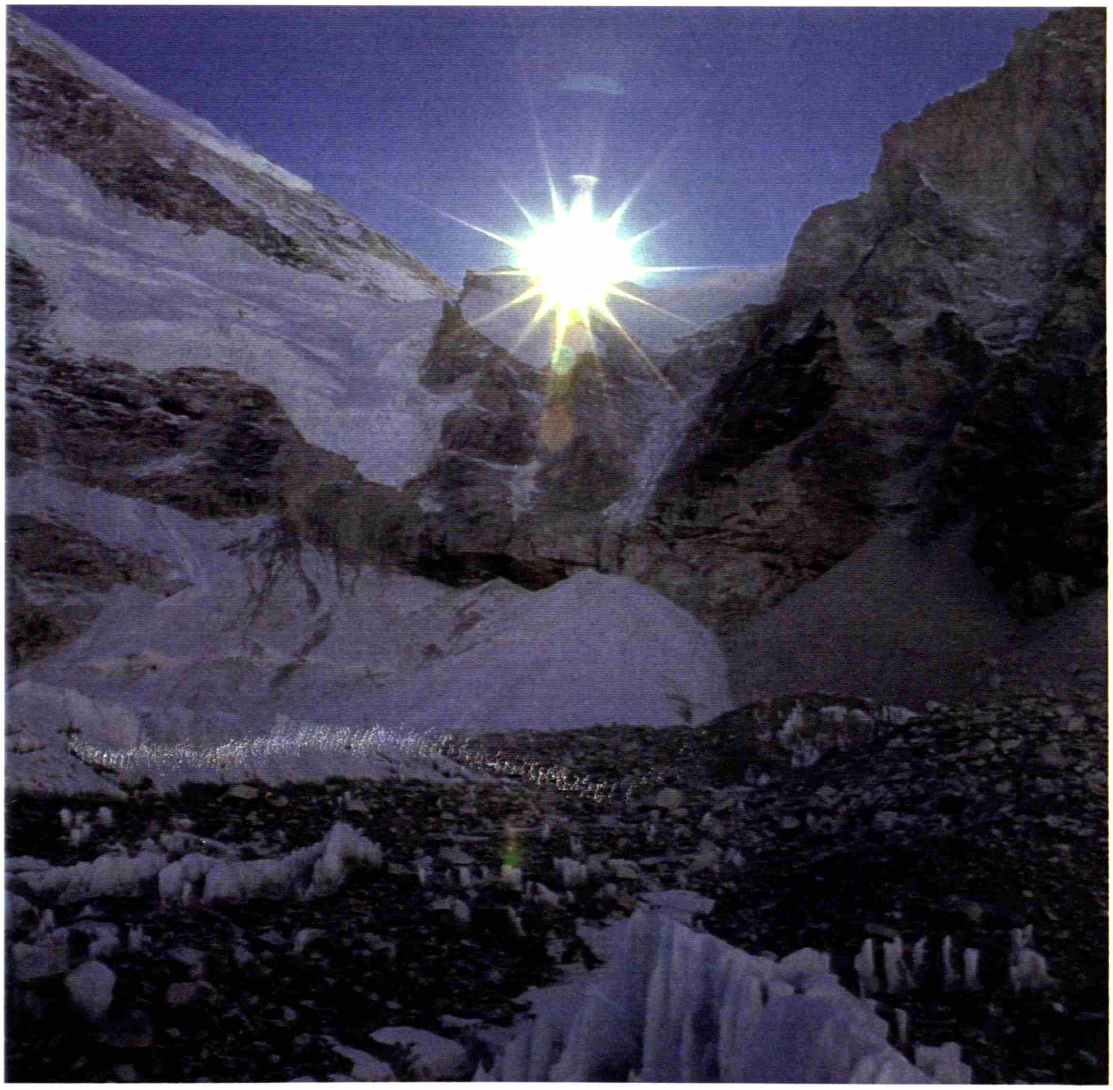

Sunrise over Lho La, photo © 1998, Matthew Lau

geoPak:

Monitoring Climbers and Climate on Mount Everest

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ACKNOWLEDGEMENTS

This thesis is for the following people, without whom, I never would have gotten up this mountain:

Mike for getting us into all of this. Rob for giving me a shovel to dig my way out. Maria for never letting me use it. All the sponsors who donated equipment and funding to make this a possibility.

Dr. Washburn for the invitation. Scott for getting us there. Ken for keeping me alive. Chris and Ed.

Ghomba for the tea. Chhongba for the pizza. The porter who hauled the 70 kg generator up ten thousand feet *on his back*. Rabi, Ram, Tika and Ang Tshering.

Andy for laying out my board. Brad for laying out my graphics. Jesse for soldering at 18,000 feet. Dave for all the insight. Wally and Charles.

Kristin, Charlotte and Joanne for keeping me sane. Erica for getting me the book. Sam and Rachel for everything. Mom and Dad.

Thank you.

Photo © 1998, Michael Hawley

Is he wearing *shorts*?

ABSTRACT

This "footprint" describes the *geoPak*, and its first test on Everest. The geoPak is a device designed to collect and transmit information about its position and surrounding environment. It uses the Global Positioning System (GPS) and low power sensors to collect information about location, temperature, humidity, air pressure, and light. A radio transmitter then sends this information to a remote base station, letting people far away monitor the 'Pak.

The geoPak is a piece of the Media Lab "Black Boxes" project, begun in February, 1997 [1]. It was designed with size and weight in mind, for use on Mt. Everest during the early climbing season of 1998.

In May of that year, the geoPaks were used to monitor four climbers during their ascent from base camp at 17,500 feet to the highest point in the world, more than two miles higher. Difficulties forced an end to tests at around 26,000 feet, but insights gained from these experiments have led to an expansion of the project with revised goals.

This thesis describes the design and implementation of the first geoPak prototypes and their use on Everest. It also to outlines how the geoPak and devices like it may someday impact not only the climbing community, but also life at home.

Photo © 1998, Jesse Darley

Moonrise over the Khumbu Icefall

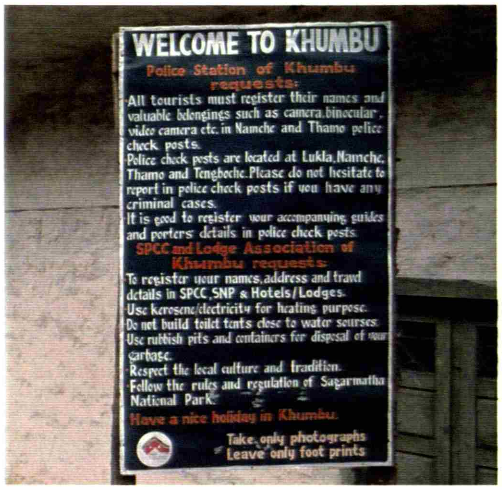


Photo © 1998, Michael Hawley

INTRODUCTION

THAT WAS THEN…

MAY 1996: DISASTER ON THE MOUNTAIN

Photo © 1996, courtesy of Ken Kamler

Ken Kamler treats Beck Weathers for frostbite after he was nearly killed in 1996.

On May 10, 1996, Beck Weathers found himself in a blizzard high on Mount Everest. Huddled with three other climbers, he found himself trapped, freezing and unable to move, unable to get back to the safety of the tents at the high camp, just 350 yards away. Other climbers from the missing climbers' expeditions, aware that their friends were out there but unable to find them, searched blindly in the storm. After several hours of stumbling around in the white out, Anatoli Boukreev at last wandered into the group. Summoning his last bit of strength, Boukreev organized the climbers who were still able to walk and returned with them to Camp Four. Weathers and the others were left for dead [2].

By the time the storm cleared, eight climbers would be dead. Weathers, having miraculously regained consciousness, would wander into camp the following afternoon under his own power and collapse in a tent. Beck, a surgeon from Dallas, Texas would survive, but eventually lose both hands to frostbite, a potentially avoidable loss, had his fellow climbers been able to locate him.

…THIS IS NOW.

MAY 1998: THE AMERICAN EVEREST EXPEDITION

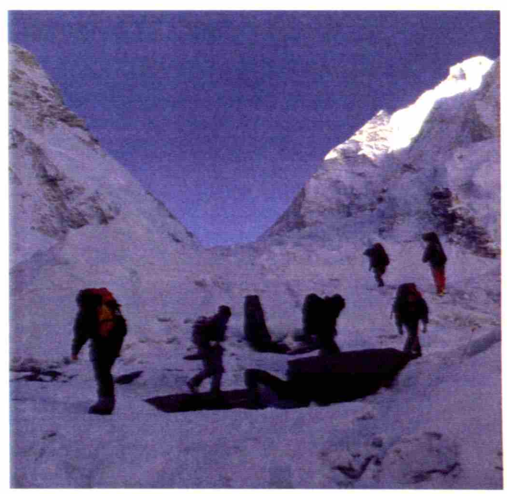


Photo © 1998, Jesse Darley

Climbers depart into the icefall for the summit.

On May 16, 1998, Wally Berg of Copper Mountain Colorado, lead guide for the American Everest Expedition, departed Everest Base Camp for the summit. In his gear, he carried a geoPak, capable of monitoring his location and the surrounding weather, and transmitting this information back down the mountain. He would carry this device to the South Col, where, in order to maximize his chances at a successful summit attempt (weight is minimized on summit day), he would leave it. With this effort, Wally would become the first climber to have his location tracked remotely while on Everest. His contribution would serve to advance the field of remote personal monitoring by giving us insight into what it takes to make a usable climbing monitor. The lessons learned from these experiments have provided the geoPak's designers countless lessons on how to properly build a remote monitoring device, even here at sea level.

GETTING FROM THEN TO NOW
THE EVEREST EXTREME EXPEDITION

In the fall of 1997, 87 year old Bradford Washburn, honorary director of the Boston Museum of Science, and lead organizer of the American Everest Expedition expressed an interest in getting MIT's Media Lab involved in his Mt. Everest project the following spring. At the same time, the NASA Commercial Space Center at Yale University, familiar with the Media Lab's "Marathon Man" project [3], asked the Lab to help with an extreme environment telemedicine project. After a January meeting of all interested parties at the New York City chapter of The Explorers' Club, the Everest Extreme Expedition (E^3) was born. MIT would organize and travel with this group, but have help with experiments from the American Everest Expedition's climbers.

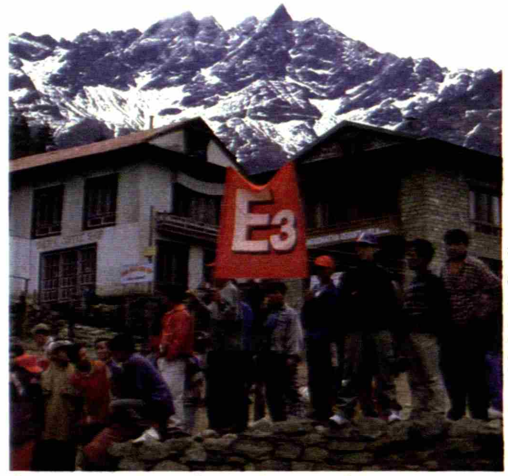


Photo © 1998, Maria Redin

A warm reception at Lukla, the start of the trek.

With a field team of three doctors, six scientists from MIT, and four others with the necessary skills to keep the rest of the crew alive while trekking through Nepal, the E^3 expedition set out with three lofty goals in mind: First, to study high altitude physiology of both western and native peoples; Second, to demonstrate telemedical principles from base camp, and last, to test devices designed to monitor conditions too remote or too dangerous for first-hand observations.

ISSUES AT HAND

This document starts by outlining work related to and leading up to the geoPak, then it describes the events of the 1998 Everest expedition. Next, it gives a technical description of the device and its protocols, and finishes with results gathered on Everest and the conclusions suggest.


A buddhist *puja*, photo © 1998, Jesse Darley

BACKGROUND

As one wise philosopher once put it, "Since the dawn of time, there have been only a handful of us that could tell where we are; navigating by the heavens, watching the movement of the sun, even sailing with a compass. Most of us just get drunk and wander around under the sky [4]." The geoPak doesn't measure anything that hasn't been measured already, but it does it in a smaller and more integrated package than has been available. This project marks the first time anyone has *climbed a mountain* while monitoring both position and weather, and all simply by carrying a small, sealed box in the top of their pack.

THE GLOBAL POSITIONING SYSTEM

Developed by the U.S. Department of Defense to track vehicles and soldiers, the Global Positioning System (GPS) is a constellation of 24 satellites in such an arrangement that at any given time, at least four are visible from any point on Earth [5]. By fixing on the radio signals these "artificial stars" broadcast, a receiver can triangulate its position in three dimensions and time to within millimeters, and accurate to the second. Ten years ago, GPS receivers were hundred pound boxes with unwieldy, meter-wide antennas to capture the weak radio signals from the satellites. Today, receivers are single board devices a few square inches in size, weighing less than an ounce.

MARATHON MAN

Photo © 1997, Matthew Lau

Celebration after 26.2 grueling miles

April 1997: The 101st Boston Marathon—Three unregistered "bandits" run the world's largest marathon… wired. Palmtop devices on their hips record samples each second of the runners' GPS location, internal temperature, footstep count, and heart rate. The loose, bulky hip pouches that hold the devices rub holes in the runners' sides, and make finishing the race painful enough that two of the runners abandon their gear at mile 20. Batteries in these devices are changed three times over the five-hour race, and the information is swapped out on PCMCIA cards and physically transported to a server for processing [3].

The rigging for this event weighed nearly three pounds, and in the end, many of the soldered connections between sensors and the microprocessor board were broken due to the intense shaking associated with running.

July 1997: The San Francisco Marathon—With the entire design and packaging overhauled, and cellular modems installed, the Marathon Man project performs admirably, following three runners from the start at the Golden Gate Bridge to the finish at Kezar Stadium. In fact, the observations are so clear that they indicate a change in one runner's stride even before he calls in to report that he's dropped out because of a foot problem [6].

Having learned of the necessity of comfort from the first marathon, the second incarnation of the Marathon Man belt weighed just over two pounds and restricted both vibration and discomfort by utilizing a specially designed neoprene belt pack.

The Marathon Man project also ran successfully two more times, once in the New York City marathon, and once as part of a US Army Research Institute for Environmental Medicine (USARIEM) project [7].

WEATHER STATIONS ON MT. EVEREST

In 1996, the year of the disasters on Everest, David Mencin and Roger Bilham of the University of Colorado, attempted to construct a weather station at the South Col on Mount Everest. Powered by solar cells and measuring temperature, air pressure, and wind speed, their station was mounted on a tripod at 26,000 feet, with enough logging capability for one year, and a supposedly "ruggedized" casing to withstand the elements [8].

Only two weeks after it was put in place, the station ceased to function. Sherpas, knowing how valuable solar cells are, and seeing them lying about as if abandoned, cut the wires and brought down the station's only means of power. Furthermore, high winds destroyed the weather station, presumably blowing its constituent pieces thousands of feet down the mountain into Tibet. The only piece left unscathed was the tripod, which David Breashears is purported to have hauled down the mountain and is now using for photography [9].

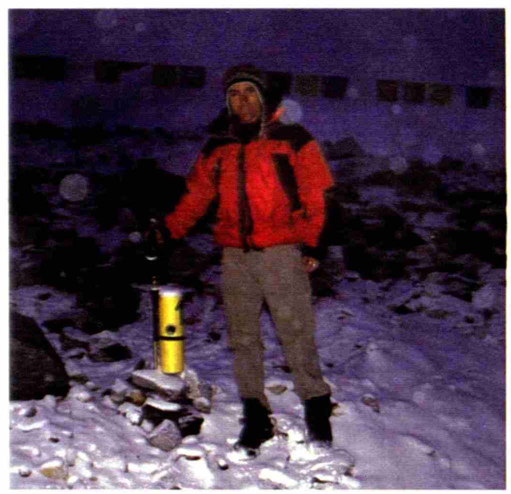


Photo © 1998, Jesse Darley

Jesse Darley with a weather station at Base Camp

In 1998, a project related to the geoPaks was to put small weather stations, sealed in tubes and with no moving parts, high on the mountain. These contained stations were designed with the same weather sensors as the geoPaks, and are equipped with custom transmitters to communicate via satellite. The hope was that, with a rugged design, and batteries sealed inside, the stations would be able to transmit for one year from their date of deployment. At the time of writing, the stations were still alive and transmitting, even though they are buried in the deep snow of the monsoon season.

In parallel with the geoPak, Bio Packs were designed to measure four vital statistics of climbers and transmit them back to base camp so that doctors at a safer altitude could monitor their health [10]. The four vital statistics monitored were: internal temperature, skin temperature, heart rate, and blood oxygen saturation. The goal of the Bio Pack project was to further the cause of medical monitoring, and, in conjunction with the geoPak, to eventually be able to relate conditions outside the body to reactions inside. As a secondary goal, the Bio Pack attempts to use a more extensible plug-and-play chain of sensors as an improvement over the existing Marathon Man technology.

THE BIO PACKS

Photo © 1998, Maria Redin

Jim Williams gets fitted with a Bio Pack over dinner.

Mother Goddess of All, photo © 1998, Jesse Darley

EVEREST 1998

The American press surrounding Mt. Everest has been, as news media will be, slightly flawed in its reporting of expeditions to the mountain in 1998. Both the American Everest Expedition and the Everest Extreme Expedition went to the mountain with scientific goals, but the media has ignored the important distinction between the two groups, namely the particular projects they worked on. E^3 was primarily interested in medical research, while the AEE performed geological research. Crossing the boundary, however, both groups collaborated on the testing of the geoPak. The following sections outline the specific goals of each group, and their role in the development and testing of the geoPak.

The expedition participants for both groups are listed in Appendix A

THE AMERICAN EVEREST EXPEDITION

The focus of the 1998 American Everest Expedition was to study geology in the Khumbu [11]. Honorary leader Brad Washburn has for years been considered one of the foremost cartographers of the Everest region. Based in Boston, Brad's team set out with the goal of using GPS to measure the world's tallest mountain. Everest is an important link in a chain of geodetic stations that stretch across the Himalaya. By studying its movement, the American Everest Expedition hopes to learn more about continental action in the region. As a secondary goal, the team wanted to help MIT with their projects on the mountain.

Photo © 1998, Jesse Darley

Charles practices installing GPS units with the sherpas.

Before departing for Nepal, Berg and Charles Corfield, principal scientist for the American Everest Expedition, came to the Media Lab to give their input on the design of the Bio Pack and geoPak, as well as to prepare MIT members for their expedition. In fact, their suggestions are partially responsible for severing the geoPak project from the Bio Packs. Separating the two eliminated the need for a wire between a climber and his backpack, and the interdependency of the systems was removed.

After the scientific expedition arrived in base camp, Berg and several members of his team spent time in our camp helping get equipment ready and giving their input on how devices should be configured in order to be usable while climbing. Then, when it was time to leave for the summit, they carried the devices with them.

THE EVEREST EXTREME EXPEDITION

Organized around the NASA CSC at Yale, the goals of the Everest Extreme Expedition were to demonstrate harsh environment telemedicine and to test experimental telemedical devices [12]. Making up this non-climbing group (The E^3 group trekked to base camp at 17,500' but did not intend to climb) were, a doctor from Yale, one from Georgetown, Ken Kamler—the doctor who had saved Beck Weathers—and four organizational people. Six scientists from MIT also traveled with this group.

Photo © 1998, Michael Hawley

The E^3 team assembled outside the medical tent.

The E^3 team arrived at base camp on May 3rd to set up camp and begin medical studies of the people there. It also began high-altitude testing of the Bio Packs and geoPaks. By the time the climbers departed for the summit, we had debugged and modified our devices to cope with the difficulties of high altitude.

After climbers began to depart for the summit, the E^3 crew became one of the many groups anxiously watching the progress of the climbers on the south side of Everest. The only difference was, the E^3 group could monitor them digitally.

THE DISTRIBUTION OF GEOPAKS

In all, three geoPaks traveled above base camp, carried by members of the AEE. Wally Berg carried one, the team of Eric Simonson and Craig Wilson carried another, and a third was taken up the mountain by climbing sherpas. A fourth remained around base camp and made several short day trips into the Khumbu Icefall with E^3 members.

Simonson and Wilson left base camp on May 15th, and Berg departed a day later. All of the 'Paks would eventually make it to the South Col, but due to a variety of factors, none of the paks would make the last day of climbing to the summit.

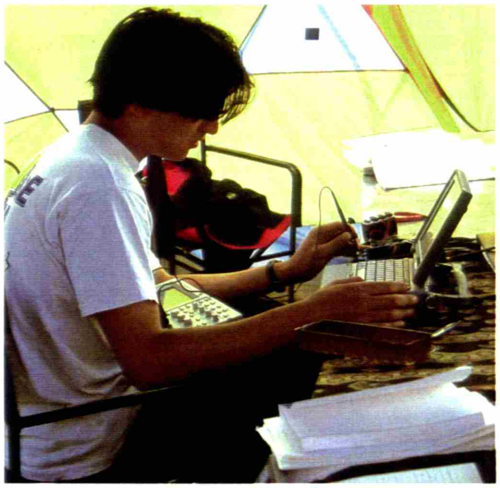


Photo © 1998, Michael Hawley

TECHNICAL SPECIFICATION

This section is included for those interested in the details of the geoPak construction. The following sections describe the components of the geoPak.

SENSORS

The geoPak architecture supports up to eight sensors, with access to four full duplex serial ports and up to five analog inputs. Serial inputs allow for more complicated integrated sensor and communication packages, while analog ports handle simpler sensors. For Mount Everest, we chose to monitor temperature, pressure, light, humidity and GPS. Other suggested measurements included compass heading and wind speed, however, these sensors were dropped to allow the package to hang off a climbers' pack.

Before leaving for Mt. Everest, the sensors were put through a series of refrigeration and heating tests to develop calibration curves for later reference (available in Appendix B).

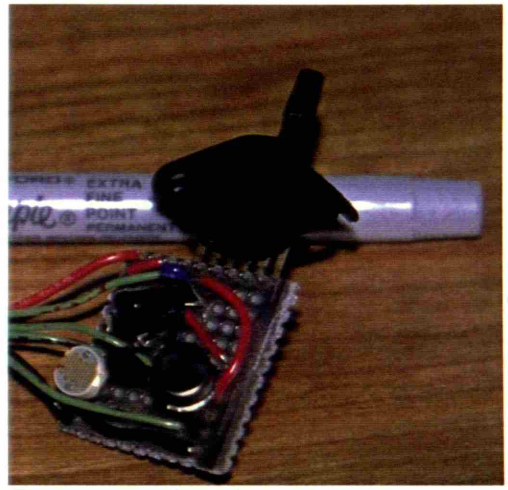


Photo © 1998, Brad Geilfuss

These sensors really are tiny.

GPS

The most complicated sensor in the geoPak array is the Trimble Lassen SK-8 OEM board [13], capable of using up to 8 GPS satellites to compute receiver position with an accuracy of two meters[1].

The SK-8 boards are configured to report the Trimble-specific TAIP protocol LN message, along with a unique identifier for each receiver, to aid in the identification of each geoPak. A description of this message is available in Appendix C.

To stand up to the harsh climate the geoPak is likely to encounter, a special, extended temperature range board is used, with an operational range of –40 C to +85C. When enabled, this device draws 200 mA @ 5V, with a backup battery draw of 2 µA @ 3.5 V.

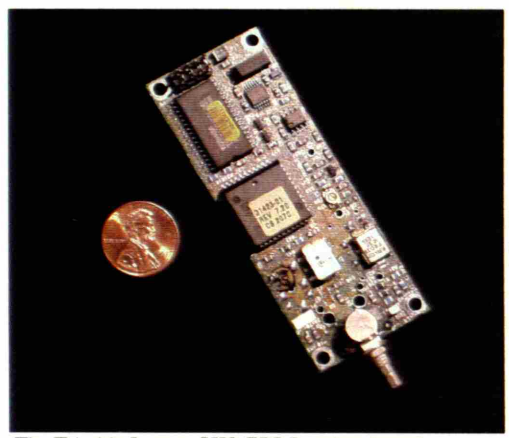


Photo © 1998, Brad Geilfuss

The Trimble Lassen-SK8 GPS Receiver board.

[1] Two-meter accuracy requires differential computation. Without this, the position solution is accurate to within 25m. Note that two receivers close to each other will have roughly the same error, so it is still possible to know a very accurate direction and distance from one receiver to another.

PRESSURE

To measure pressure, the geoPak uses a Motorola MPX5100AP absolute pressure sensor, which has an output voltage that varies linearly with pressure [14]. It has a maximum error of 2.5% from 0 to 85 C (and a 7.5% maximum error at –40 C), and its sensitivity in the 0-1 atmosphere range covers all altitudes encountered in mountain climbing. The accuracy of this measurement is enough to give a barometric reading, with the added advantage of being a rough altimeter.

This sensor was chosen because of its relatively low power requirements (7.0 mA @ 5V), and its very fast response time (from power-up, it requires only 1.0 mS for a stable reading), making it ideal for the geoPak.

Photo © 1998, Brad Geilfuss

A Motorola MPX5100AP pressure sensor.

LIGHT

A cadmium sulfide photoresistor, in series with a fixed 10 kΩ resistor provided, essentially, a single-pixel, eight bit reading of the ambient light near the climber. The goal of the sensor is to discern between darkness, bright sunlight, and twilight or artificial light.

With this measurement, data analysis can include the association of a fall in temperature with the setting of the sun or the 'Pak moving into a shadow. Even though the reading is rather imprecise, combined with other measurements, it allows the observer (be it human or computer) another clue as to what is taking place with the geoPak.

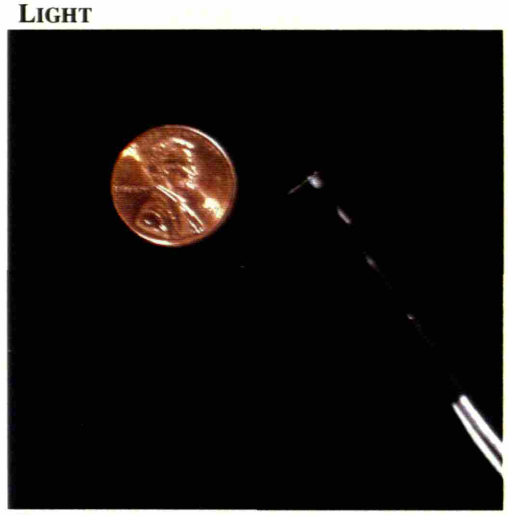


Photo © 1998, Brad Geilfuss

The light sensor: a one-pixel camera.

HUMIDITY

Humidity is measured by a Panametrics MiniCap 2 thin-film capacitive relative humidity (RH) sensor [16]. This element was incorporated into the package when the original part (a Honeywell IH-3605 linear voltage device) became unavailable shortly before the Mount Everest project executed. It humidity sensor measures humidity from 0 to 100% in temperature ranges from –40C to +180C. On Everest, scientists initially made the claim that humidity would be near zero, however climbers had made claims of seeing free standing pools of water as high as 26,000 feet.

Photo © 1998, Brad Geilfuss

How wet does it get?

Temperature

A National Semiconductor LM335 provides temperature data [15]. This is a relatively standard temperature sensor with a very low supply current requirement (the LM335 can operate as low as 400μA @ 5V) which maintains a linear output accurate to within one degree between –40 C and +100 C.

The Microcontroller

The custom electronics on the geoPak are built around a Microchip PIC16C76 microcontroller [17]. With 8K of program memory, and 368 bytes of data memory, the 16C76 is large enough to handle all of the data generated by the sensor arrays and run the control circuitry necessary for memory and radio work. Operating at 8 MHz, the 16C76 draws less than 10 mA @ 5V, and has an operating temperature range from –55C to +125C.

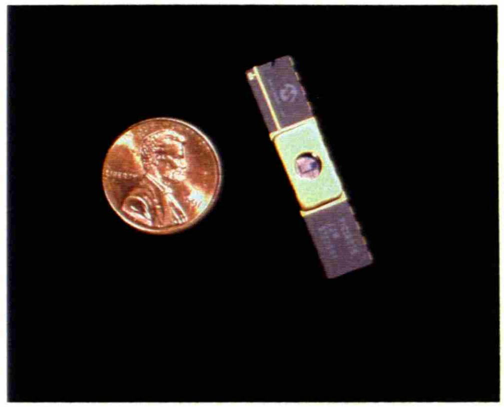


Photo © 1998, Brad Geilfuss

PIC16C76: the brains of the whole operation.

In order to minimize space and loose wires, a custom PCB was designed to connect each of the components. The board measures 3x1.5", and has mounting holes to mate directly with the GPS receiver. Headers provide pin-for-pin connectivity with the radios, as well as standard serial and TTL data outputs. One unused header is configured to connect directly to a Precision Navigation electromagnetic compass and inclinometer, allowing the geoPak to be used for navigation purposes.

Memory

On-board logging was accomplished with a Macronix MX25L4004, with 536 kilobytes of flash EEPROM storage space [18]. The MX25L4004 is a hybrid SRAM/EEPROM device, using a quick access buffer to allow fast access to 536 byte pages via a serial interface. Data can be written and read very quickly via an unstable SRAM cache, and the chip will automatically update the contents of the slower but stable EEPROM.

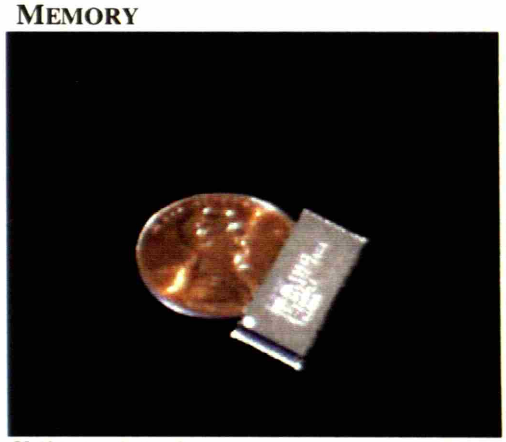


Photo © 1998, Brad Geilfuss

Half a megabyte of memory.

At a nominal logging rate of one sample per six minutes, the 536 kB of storage can hold up to ten days worth of data, and at an average draw of 3.41μA @ 3V, is one of the lowest power consumers in the geoPak.

Radio

A Freewave DGR-115, a frequency hopping, 902-928 MHz, transceiver is built into the geoPak for wireless data retrieval [19]. This single-board unit provides up to twenty miles line-of-sight communication with deployed 'Paks, so, given a good observation point, is an excellent platform for observing mountain climbers.

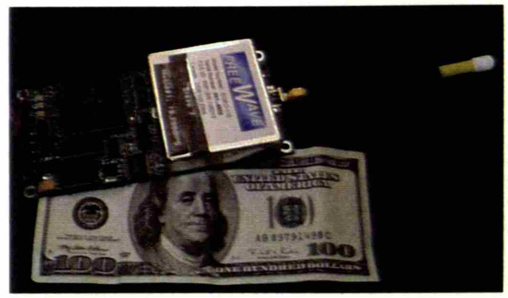


Photo © 1998, Matthew Lau

Radio communication is precious.

This piece is the key to remote monitoring. The most difficult part of observing data collected remotely, as the Black Box project has already discovered, is getting the data from one point to another. The Freewaves contained their own algorithms for routing and repeating, and they allowed multiple geoPaks to communicate over a single channel to one base station receiver.

On Mount Everest, the geoPaks were configured for 19.2k data rates, with an average duty cycle of 8 seconds every 6 minutes, making for an average current draw of 4.9 mA @ 9V.

POWER

Power for the geoPak is provided by four 9-volt lithium batteries in parallel. Each cell is rated at 1200 mAh with an operational temperature range of –40C to 60C.

A PowerTrends PT5100 switching regulator provides power to the 5V systems, while the 3V systems receive power from a Toko TK11330BM switching regulator [20][21]. The Freewave radio is connected directly to the batteries via a relay controlled by the microcontroller. By switching off sensors and the radio between samples, this power configuration can run the geoPak for eight days without interruption.

THE GEOPACKET

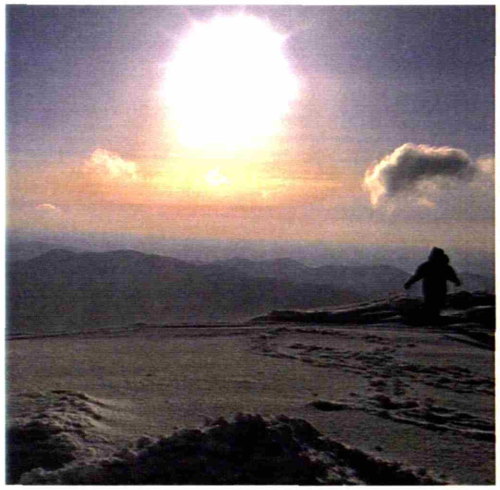
Data is transmitted and stored in the same format. A single, 219-byte packet contains all of the sensor information, encoded in a near human-readable format. Each line of the packet is checksummed using a sixteen bit CRC. In addition, the whole packet is checked using the same CRC algorithm. This allows the user to identify errors in transmission or storage, and isolate flawed readings without having to discard entire geoPackets.

```
(geoP 0007 000b
        (lite 0007 02)f1ce
        (temp 0007 d2)4c9f
        (humd 0007 a1)f450
        (pres 0007 41)59dd
        (tgps 0007 33308400+2797359
                   99+0869301230+02
                   60948604058510DB
                   243730EE00000000
                   0012;*4E)1155
)abbe
```

A typical geoPacket

On Mount Everest, communication between the geoPaks and the base station was done without acknowledgement packets, relying on memory to hold on to dropped packets. Using the Freewave radios, a two-way protocol could be introduced to provide for the resending of flawed or dropped packets, as well as for live-time reconfiguration of the geoPak. This would let base camp put a 'Pak into "emergency mode" for constant sampling, or feed differential correction information directly to the GPS receiver.

The format for the geoPacket is described in more detail in Appendix D.



Dawn on Mt. Washington, photo © 1998, Matthew Lau

RESULTS

This section details the geoPak's 1998 expedition on Mount Everest. Overall, results were mixed, however it is worth indicating that the purpose of the expedition was to further the development of the geoPak and other experimental devices, not to use these devices to perform a study.

The first few sections of this chapter discuss unanticipated difficulties, and failures in the system, while the last section shows the data that was collected. In short, the reader gets the bad news first, and the good news last.

WHAT WENT WRONG

As with any project, not everything went exactly as planned on Mount Everest. To compound the typical problems caused by broken or malfunctioning components, environmental conditions and a lack of oxygen decreased the reliability of both the electrical components and the people working on them.

BROKEN RELAYS

Upon arriving at Everest Base Camp, at an altitude the GPS receivers indicated at 17,329 feet[2], we unpacked and tested the geoPaks. The first and most obvious altitude-induced failure was in the relays controlling the sensor and radio systems. Even though the relays were specified to operate in extreme cold, they for some reason, had difficulty switching in the high altitude. Using the limited resources available (if we didn't bring it, it wasn't there), we replaced the relays with a makeshift transistor circuit.

The replacement circuit allowed for a small amount of "bleed" current, which, although small, we estimated would probably cut two days off the useful lifetime of the geoPaks.

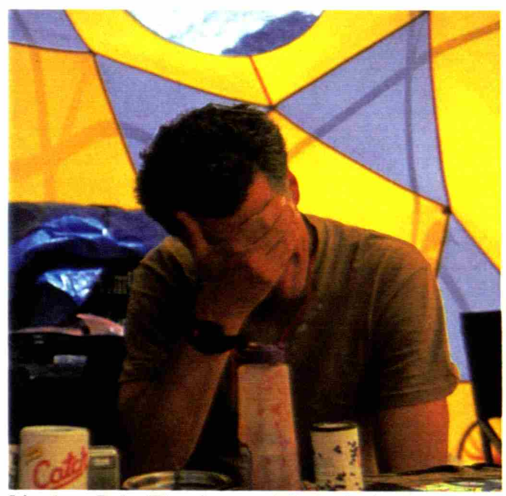


Photo © 1998, Jesse Darley

It's okay, Rob. There's more jelly in the kitchen tent.

[2] GPS measurements are made in the WGS-84 coordinate system, based on the distance from the center of the earth. Traditional measurements "above sea level" are hard to correlate to WGS-84 coordinates, because factors involving the Earth's non-spherical geoid are hard to measure. The traditionally accepted altitude of base camp is 17,500 feet above sea level.

The Radio Shadow

In the days before the ascent, we were faced with the challenge of finding a suitable place to place a repeater in order to maintain line-of-sight radio communications. Being restricted to staying below the Khumbu Icefall on the route, our only real chance for good coverage was to place the repeater behind base camp on the peak of Kala Pattar, at 18,800 feet, on the opposite edge of the Khumbu Glacier from the climbing route.

In this position, the repeater would be able to maintain line-of-sight from base camp to the top of the icefall, and above camp two. The unfortunate part of this location is that, the climbers would be out of view of the repeater in a "radio shadow" behind the west shoulder of Everest from the top of the icefall until just above camp two. This would cause one full day of occlusion, during which time the 'Paks would be out of range. Short on time and unable to find a more suitable location, it was decided to let the units log data during the silence.

GPS Antenna Placement

Probably the most avoidable human factors came from the placement of the GPS antennas. On an ascent of Mount Everest, climbers are, by necessity, extremely concerned with the positioning of weight in their climbing packs. Because of this, the geoPaks were sometimes buried so that the GPS antenna could not receive satellite signals. Reluctant to hang the geoPak on the exterior of their riggings, climbers would, on occasion, put them deep in their backpacks, where the light and GPS sensors were useless. Other data was collected during those times, but there are still holes in the data resulting from these placements.

Battery Failure

Everything built into the geoPak was specified to operate down to –40 C, but, in a somewhat significant oversight, not everything was tested or rated to operate at half an atmosphere. As a result, some batteries leaked fluid somewhere between 18,000 feet (in the icefall), and 26,000 feet (the South Col). This failure was by far the most significant in failure in the geoPak, and caused the greatest loss of data. In one pack, three of four batteries burst, causing the radio to shut down, and the logging to work only during the day, when the one remaining battery was warm enough to provide enough current to run the system.

As a result of failing radio communications and having no way of knowing if the devices were logging even though they weren't transmitting, the decision to not carry the geoPaks to the summit was made as to not jeopardize any climber's summit bid.

WHAT WENT RIGHT

Even with all of the failures, the geoPak project on Mount Everest still had its successes. In fact, breaking components and discovering design flaws were both goals of taking them to altitude. In addition, the 'Paks were able to collect some data. The next section describes what was brought back.

DATA SETS

The map at the bottom of this page shows the GPS data collected from geoPak #5, carried by Wally Berg on his ascent of Mount Everest. The left set of points is base camp and into the icefall, and the right set of points is the South Col. The geoPak was stored deep in his pack during the climb, and the GPS unit did not record any measurements.

Figure 1: GPS Data at Base Camp and the South Col

The next two figures show one day's worth of environmental data for both base camp and the South Col points. The base camp graph shows the relatively warm temperatures during the day in the bright sunlight, and then the gradual darkening as the sun goes behind a ridge in the evening, and the corresponding temperature drop. The South Col shows a similar phenomenon.

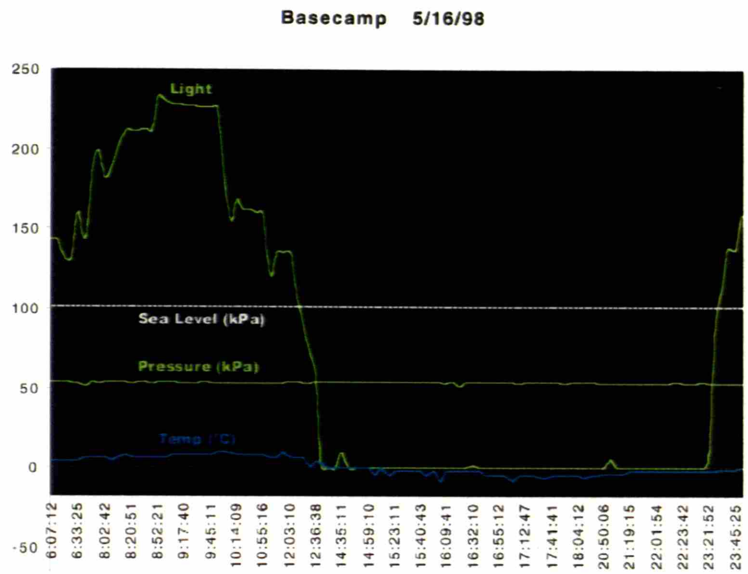


Figure 2: Light, Pressure and Temperature from Base Camp

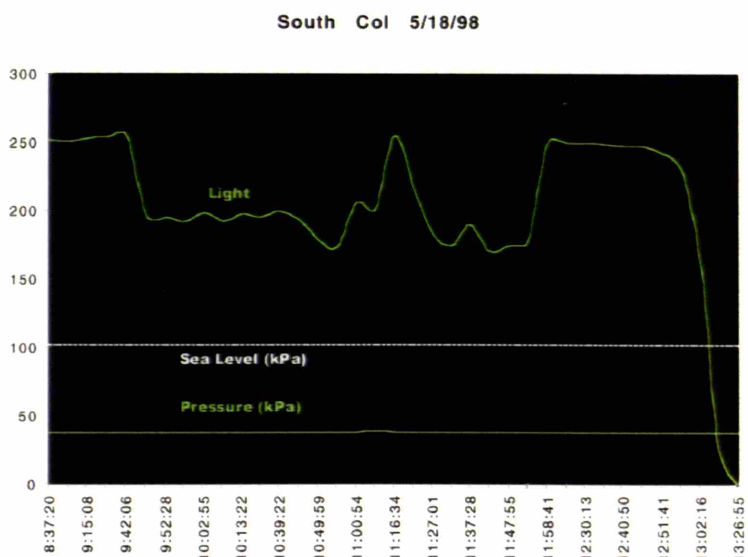


Figure 3: Light and Pressure from the South Col

Workin' on the Yak Train, photo © 1998, Jesse Darley

CONCLUSIONS

While the lack of a large body of data from Mount Everest is a significant disappointment, the goal of the expedition was, as stated before, to advance the development of the geoPak and other remote monitoring devices. In that regard, the trip has been considered by all involved to be a success. This section outlines the conclusions arrived at as a result of the expedition.

THE NEED FOR A GEOPAK

The initial purpose of the geoPak was to monitor climbers for medical purposes, to try to associate medical data with environmental data, and to observe how the latter effects the former. While this remains a goal of the geoPak project, it became obvious on the mountain that a primary benefit of deploying geoPaks on a wide scale would be purely safety related.


Photo © 1998, Maria Redin

Ken was initially skeptical about the geoPak.

The disaster in 1996 is far from an isolated incident. As the E^3 group was trekking into base camp, a climber was reported missing somewhere between Camp One and Camp Two. For four hours, there was high drama on the mountain as other members of his team scoured the face just below Camp Two, where they thought he had fallen into a crevasse. In the end, it would turn out that he had exhausted himself, climbed into a tent and fallen asleep, ignoring all radio calls trying to find him.

In cases like this, as well as in real emergencies, the geoPak would allow team members at base camp to direct searchers to missing climbers. With basic life sign monitoring, base camp members could also monitor who was alive, so that in a disaster like the one in 1996, searchers could focus efforts on finding climbers who were still alive or have a greater chance of surviving. Of the geoPak, Dr. Kamler has said, “If we had had this technology working in ’96, it would have saved lives [22].”

RADIO COVERAGE

Having investigated many types of radios, we are convinced that a frequency-hopping radio, like the Freewave, is the correct type to use on Mount Everest, and in many wilderness situations. The low power requirements make it nearly ideal for lightweight situations, but they also reduce power and force a near line-of-sight situation. This makes it difficult to keep communications channels open when there are obstacles in the way. Future plans for radio monitoring on Everest include placing radio repeaters above the icefall to maintain a reliable link on the part of the mountain that was in the "shadow" in 1998. Experiments involving radio transmission of GPS data from the summit to base camp did, however, prove that radio performance over long distances is excellent.

This current configuration is tailored to Everest, but communications is a fragile platform. If the geoPak is to be redeployed in other situations, it will be necessary to replace the radios with other devices better suited to the conditions. In North America, established mobile protocols such as CDPD and cellular provide a widespread solution to these difficulties.

MEMORY

The geoPak's memory module proved itself adequate in its performance, but extracting data from recovered units would have been much easier if the memory had been removable. Instead of opening the geoPak to put it into data-recovery mode, it would be much easier to have removable media to store the data. Future designs of the geoPak are investigating the possibility of using PCMCIA-type cards as storage.

HUMAN FACTORS

The geoPak is as small as was feasible for a prototype, multi-board device, and 1.4 pounds does not seem like a lot of weight to carry in a backpack. Mountain climbers, however, carry only about fifteen to twenty pounds of (non-clothing) equipment on their final day of climbing, and two pounds gets excessive. On the subject of weight, a veteran mountaineer remarked, "Climbers cut their toothbrushes in half to minimize the weight they carry. Anything you can do to cut down how much [the geoPaks] weigh, do it [23]."

Minimization of components continues naturally. The GPS is responsible for almost half the weight of the package (considering receiver, antenna, and power requirements), but smaller GPS boards requiring less power continue to be introduced. Even so, size will continue be an issue until the geoPak can be put on a single board with all components integrated.

DATA DISPLAYS

In recovering data from the geoPak, it became apparent that existing numerical displays and quantitative graphs are adequate only for a small set of people trained to understand the implications of environmental readings. For most people, temperature is about the only variable that can be understood with any intuition. Knowing that the humidity is 32% doesn't mean very much to the average person. Likewise, knowing a set of GPS coordinates isn't helpful without a very detailed map of the area, or directions to a destination.

Visualize, Oliver Roup's data display system

Brad Geilfuss and Oliver Roup have been developing systems to display information collected by the geoPak and related systems. They have early versions of software which allow the viewer to playback information to watch the data and how it changes, and to play back events chronologically and show how variations in some conditions are preceded or followed by events in others.

Matthew Gray has developed a method of "cluster weighted modeling" to detect events and, much like neural networking, "train" the modeler to recognize certain situations and identify particular patterns [24]. The focus of this work has been to identify physiological events, using the Marathon Man technology, but the geoPak project has given him access to a new set of environmental data to work with.

IMPLICATIONS

The geoPak is but another step in the long chain of projects leading to full scale, non-invasive remote personal monitoring. With each step, we find a new application. It is easy to see the benefits of such devices in the wilderness, but the larger impact may be closer to home. Skiers have many of the same needs and dangers as mountain climbers do; the ski patrol could benefit immensely from distributing geoPaks. Similarly, cameras that log their position and attitude with each frame would make self-documenting photographs. Just about anything that moves—cars, busses, bikes—could be outfitted with a 'Pak to report its position. Centralized machines could analyze commute patterns and localized road conditions to reduce congestion. Once we start really tracking *things,* we'll be able to alleviate problems related to motion.

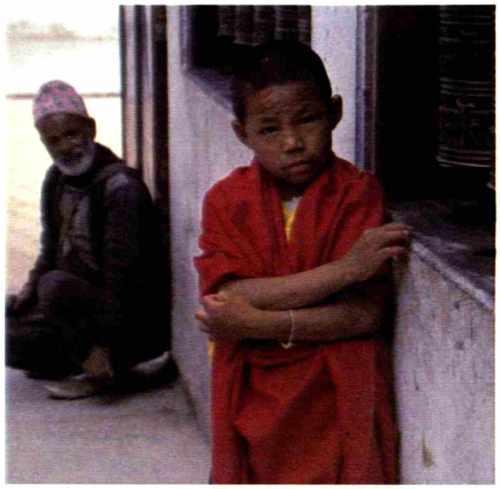
FUTURE WORK

In addition to continued work on the geoPak, new devices are continually being developed in the field of remote personal monitoring. Recently, a prototype "Bio Suit" was tested in Italy to monitor a professional motorcycle rider's comfort and safety. Current work on the suit involves using sensors incorporated into his safety gear to deploy airbags in the suit to help prevent injury in the event of a crash [25]. Sensors and research from the geoPak have contributed to this project.

We plan to continue the geoPak project and to redesign the system with an eye towards making it more of a tracking device instead of a measuring device. Perhaps next year, on Mount Everest, every climber will have their own "little black box" that keeps base camp apprised of their situation.

Photo © 1998, Maria Redin

The end of another day in the Khumbu.



A young lama, photo © 1998, Maria Redin

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A young porter boy, photo © 1998, Jesse Darley

APPENDICES

APPENDIX A: EXPEDITION TEAM MEMBERS

The 1998 American Everest Expedition:

Bradford Washburn, Honorary Leader
Wally Berg, Expedition Leader
Charles Corfield, Science Manager
David Mencin, Base Camp Manager
Eric Simonson
Greg Wilson

The 1998 Everest Extreme Expedition:

Scott Hamilton, Expedition Leader
Dr. Kenneth Kamler, Expedition Doctor
Dr. Christian Macedonia, Georgetown
Dr. Vincent Grasso, Yale/Nasa CSC
Edward Mattes
Professor Michael Hawley, MIT
Jesse Darley, MIT
Matthew Lau, MIT
Natalia Marmasse, MIT
R. Dunbar Poor, MIT
Maria Redin, MIT
Richard Satava, Jr., Base Camp Manager
James Bruton, Communications Specialist

These tests allowed us to build calibration curves for the sensors over the anticipated temperature range to be encountered on Mount Everest. Note the temperature compensation for the pressure sensor until zero C.

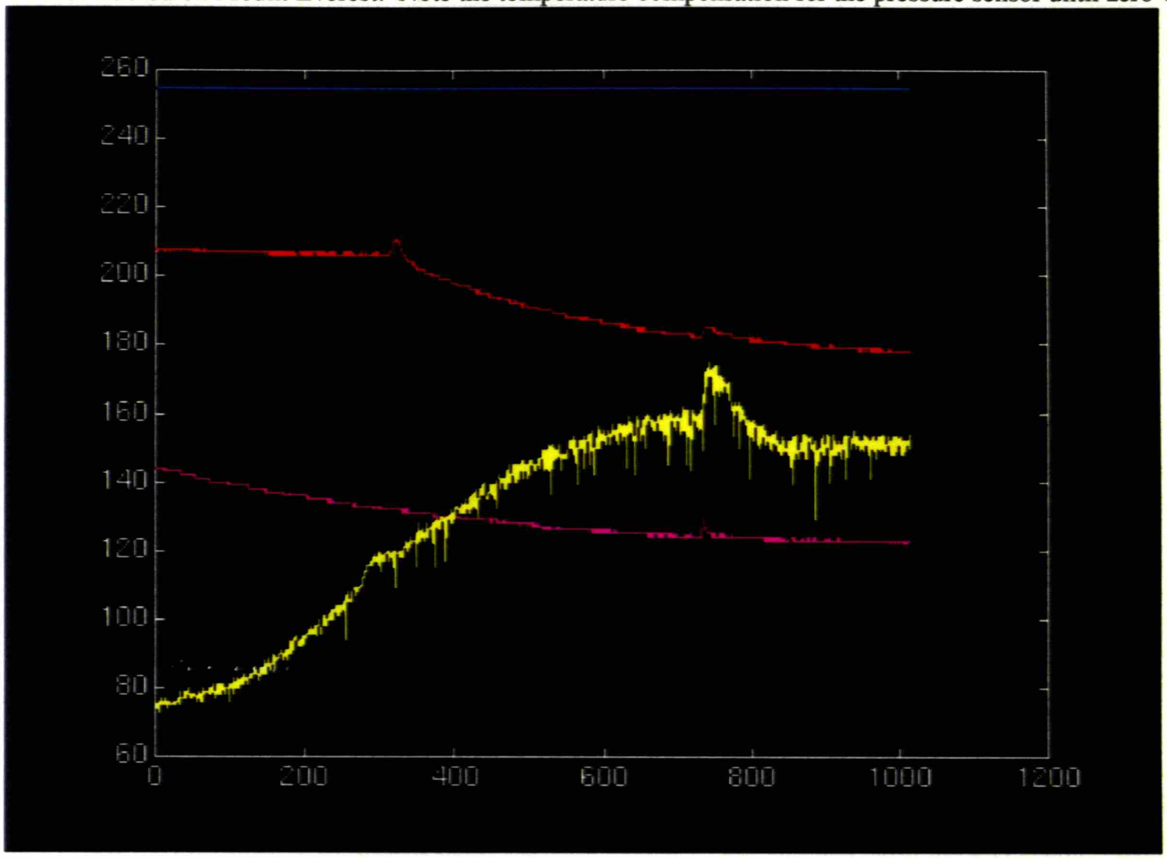

Figure 4: Cooling to –30C on 13Mar98

Light = blue
255 = Dark, 0 = Bright

Pressure (in kPa) = (red/255 + 0.095) * 111.11

Temperature (in K) = magenta * 1.96

Relative Humidity (%) = yellow * 5/255

Notes: Time (along the horizontal axis) is measured in one second epochs for this experiment.
Spikes at approximately t = 700 seconds are a result of the refrigerator door being opened.
Humidity was uncontrolled in this experiment.

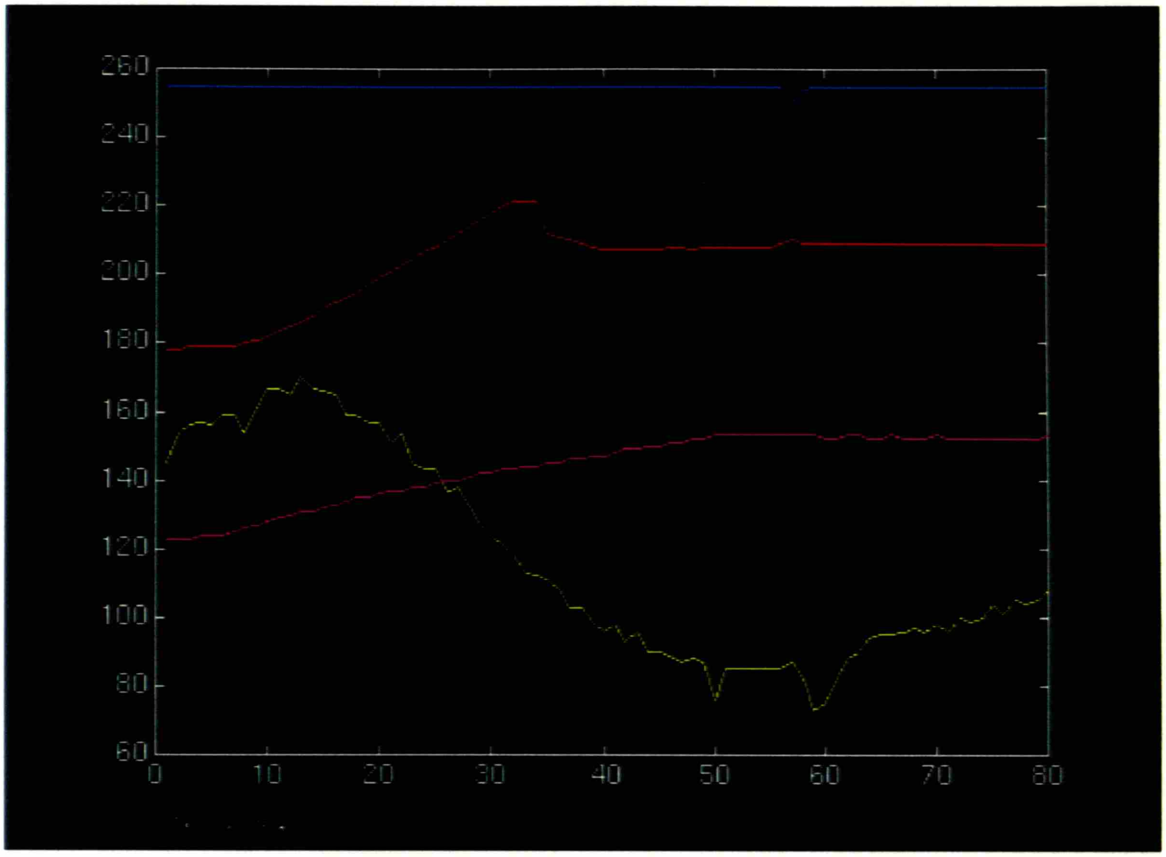

Figure 5: Warming from –30C to 30C on 13Mar98

Light = blue
255 = Dark, 0 = Bright

Pressure (in kPa) = (red/255 + 0.095) * 111.11

Temperature (in K) = magenta * 1.96

Relative Humidity (%) = yellow * 5/255

Notes: Time (along the horizontal axis) is measured in 10 second epochs for this experiment.
Spikes at approximately t = 590 seconds are a result of the refrigerator door being opened.
Humidity was uncontrolled in this experiment.

APPENDIX C: TRIMBLE TAIP "LN" MESSAGE

The Trimble TAIP "LN" message has the following format:

AAAAABBBCCCDDDDDDDEEEEFFFFFFFGGGGGGGHHIIIJKKKKLMMMNOOPPQQPPQQ...PPQQRRRRRRRRRRST

These datum correspond to the following variables:

Table 1: Trimble "LN" message datum

Datum	# of Chars	Item	Units
AAAAA.BBB	8	GPS Time of Day	Seconds
CCC.DDDDDDD	10	Latitude	Degrees
EEEE.FFFFFFF	11	Longitude	Degrees
GGGGGGG.HH	9	WGS-84 Altitude	Feet
III.J	4	Horizontal Speed	MPH
KKKK.L	5	Vertical Speed	MPH
MMM.N	4	Heading	Degrees
OO	2	Number of Satellites Used	
PP	2[†]	Satellite ID	
QQ	2[†]	Differential Correction Information	
RRRRRRRRRR	10	Reserved Space	
S	1	Accuracy of Fix	0 = 2D 1 = 3D 2 = 2D Differential 3 = 3D Differential 8 = Degraded 9 = Unknown
T	1	Age of Data	2 = Fresh (<10 seconds old) 1 = Old (>10 seconds old) 0 = Not Available
Total:	65 + 4 times the number of satellites used.		

[†] There will be a pair of PPQQ variables for each satellite used (transmitted in the OO variable).

This table is also available in the Trimble Lassen-SK8 System Designer Reference Manual, p. C-16

The geoPacket is formatted in the following manner (variable fields in italics):

```
(geoP IDID PKNO
        (lite IDID LT)CS01
        (temp IDID TP)CS02
        (humd IDID HU)CS03
        (pres IDID PR)CS04
        (tgps IDID <TRIMBLE LN MESSAGE>;TCS)CS05
)CSPK
```

The datum in the geoPacket correspond to the following values:

Table 2: geoPacket datum.

Datum	**# of chars**	**Item**	**Formula to Recover Data**	**Units**
IDID	4	geoPak ID		
PKNO	4	geoPacket Number		
LT	2	Light[†]	*LT* * 5/255	0 = dark 1 = light
TP	2	Temperature[†]		K
HU	2	Humidity[†]	*HU* * 5/255	%
PR	2	Pressure[†]	(*PR* *255 + 0.095) * 111.11	kPa
<TRIMBLE MESSAGE>	70	Trimble "LN" message with reserved space removed and eight satellites worth of differential information	See Appendix B	
TCS	3	Checksum for Trimble LN Message		
CS01...CS04	4 (each)	CRC for last respective lines (parentheses included)	See below	
CSPK	4	CRC for geoPacket (parentheses included)	See below	
Total:	219 (including fixed text)			

[†] The values in these fields are in hexadecimal format.

To calculate each CRC, as each character is printed, the16-bit CRC value is rotated left two bit positions, and the character's ASCII value is added to it. In C (using a sixteen bit int), the function looks like:

```
int computeCRC(char c, int crc) {
   ROTATE_LEFT(&crc, 2);
   crc += c;
   return(crc);
}
```